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Research sized wind turbine blade modal tests: comparison of the impact excitation with shaker excitation.

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Abstract. Modern wind turbine blades are being tested for certification purposes in accordance to the IEC-64100 standard. Part 23 of the norm details the requirements for the full scale structural testing of rotor blades. As a minimum, it requires measurement of the first and second flap wise and first edge wise natural frequencies. It lists damping and mode shapes as other blade properties which may be of interest and optionally measured. The paper presents the modal model parameters estimation based on the experimental modal analysis. In two tests performed, the input force has been introduced through impact hammer and two electrodynamic shakers excitation. Several first modes had been identified for both excitation methods, including first torsional mode of the investigated blade. Results of the modal tests can be used to (a) provide more detailed information about the structural dynamics characteristics of the blade and (b) improve the design by adjusting the dynamic properties of the blade to some desired condition.

Keywords:

experimental modal analysis, wind turbine blade, structural dynamics identification,

1. Introduction

Wind turbine blades certification [1] demands full scale structural tests for determining the blade properties. It comprises mainly of the static tests to verify the structural strength and fatigue tests in order to ensure the designed lifetime of 20-25 years.

In the presented research, the experimental based estimation of the modal model parameters is performed. In addition to the natural frequencies values, the corresponding mode shapes and damping ratios has been estimated [2]. Investigated blade requires appropriate excitation for the adequate identification of the modes and mode shapes [3,4]. Provision of the sufficient energy for the vibration excitation requires a dedicated test setup and installation of the often heavy and stiff mounts for the load attachment. In turn, the measured system comprises of the object of investigation and the additional instrumentation. The mass, stiffness and damping of the added equipment modify the measured characteristics of the tested blade. In the presented paper the two different excitation methods were investigated to assess the trade off between test simplicity and results accuracy. The values have been

compared to the results of the theoretical modal analysis performed with the use of the high fidelity finite element method (FEM) model.

2. Research methodology and approach

The object of investigation is 14,3 [m] long wind turbine blade made of the Glass Fiber Reinforced Plastics. Multiple modal tests have been performed to identify the most reliable and time efficient method to identify modes for such a structure.

2.1. Test setup

The investigated blade has been supported by two elastic cords to provide free-free boundary conditions as presented in Figure 1.

To identify the best experimental setup, the measurement campaign was designed to excite the structure with both modal hammer and shakers. To optimally excite the blade, it was decided to excite the structure both in the edgewise and flapwise directions, and at different locations so that the energy could be best spread throughout the structure. Consequently, the two shakers were positioned one at approximately 4.5 m from the blade root at the suction side surface of the blade exciting the flapwise direction, and one at 8 m from the root on the leading edge exciting the edgewise mode, similarly to the approach adopted in [6]. Impacts with the hammer were applied at the same locations. The hardware selected for this test included a pair of electrodynamic shakers rated at 100N with amplifiers and a modal sledge hammer weighting 1kg with a soft tip to ensure a good excitation between 3 and 150 Hz. Both connections between the shakers and the blade were instrumented with a load cell to accurately measure the applied force; for impact testing, the force sensor embedded in the hammer was used.

Finally, to be able to cover the entire surface of the blade, a dense grid of 120 measurement points has been defined. In order to reduce the mass loading from the transducers [7] the set of 15 available triaxial accelerometers has been distributed over fifteen equidistant cross sections ranging from the root of the blade to the tip. The same measurement has been repeated 8 times by roving the available accelerometers over different airfoil locations.

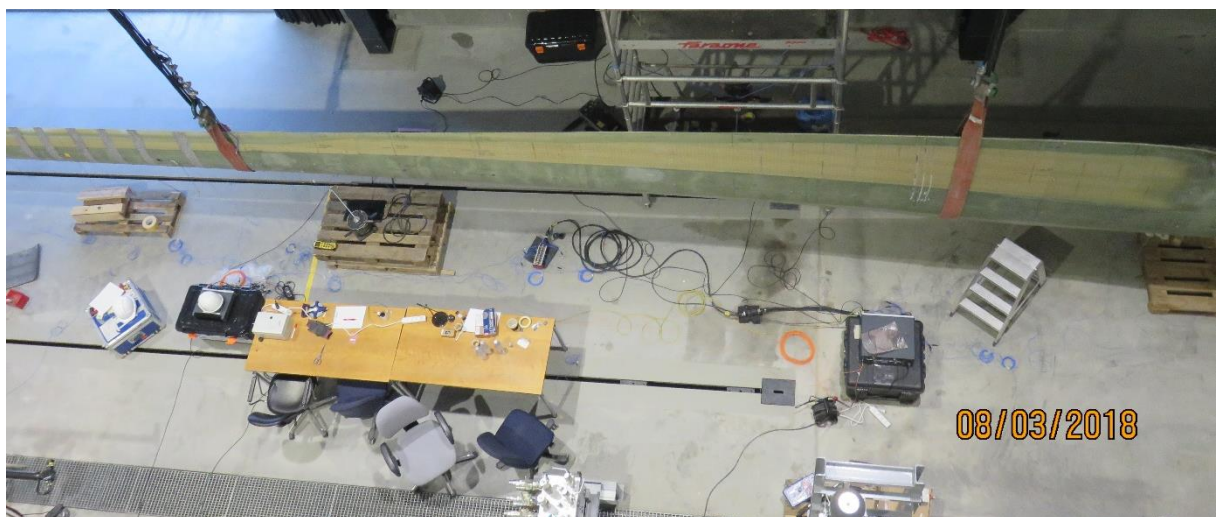


Figure 1 Top view of the wind turbine blade test setup. Blade is supported with two elastic cords. Both electrodynamic shakers are attached to the blade. Sensors are connected to the two data acquisition modules.

2.1.1. Optical accelerometer has been used for the purpose of the comparison of the metal free transducer with the traditional piezoelectric accelerometer.

All-optical sensors are ideal for applications involving harsh environments, distributed networks and remote sensing. For the vibration acceleration measurement all optical, frequency modulated, Micro-

Electro-Mechanical Systems (MEMS) sensor has been used. The sensor is a silicon microchip with integrated optical components. Spectrogram recorded during the measurement is presented on the Figure 2. Application of the electrical and optical sensors has provided useful insights about the feasibility of the optical technology application for the wind turbine blade applications.

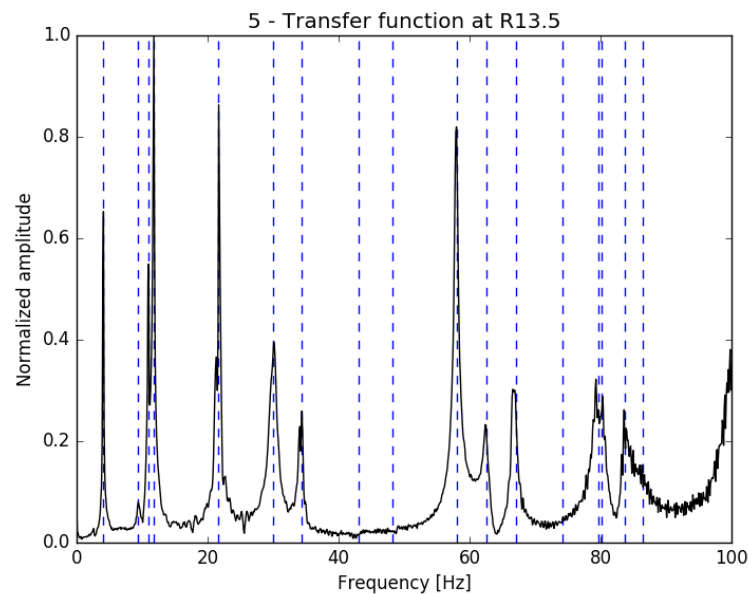


Figure 2 Frequency Transfer Function from optical accelerometer. Blue dashed lines denote the spectral lines identified from the test with the use of the electrical sensors.

3. Measurement and simulation results

3.1. Comparison of shaker and hammer FRF measurements

When performing a roving test, repeatability in the excitation is a key aspect to ensure all data can be processed together and global results derived. Shaker excitation has a clear advantage over hammer excitation, as the force profile is defined by the user; on the contrary, when doing impact testing, the ability of the user in applying always the same impact plays a crucial role. Figure 3 shows the Driving Point FRFs measured during the 8 runs with hammer and shaker excitation in both direction. When looking at the results in the edgewise direction, we can observe very repeatable FRFs regardless of the excitation technique. Some extra variability however is visible in the Impact testing results, in particular at higher frequencies and with a generally higher noise level. However, the flapwise results show very poor repeatability with shaker excitation. This is due to the fact that in this direction the shaker was often detaching from the blade because of the former pendulum motion and the necessity of using glue to avoid damaging the blade with fixed mechanical connection. In this case, consistently exciting with the hammer was much simpler.

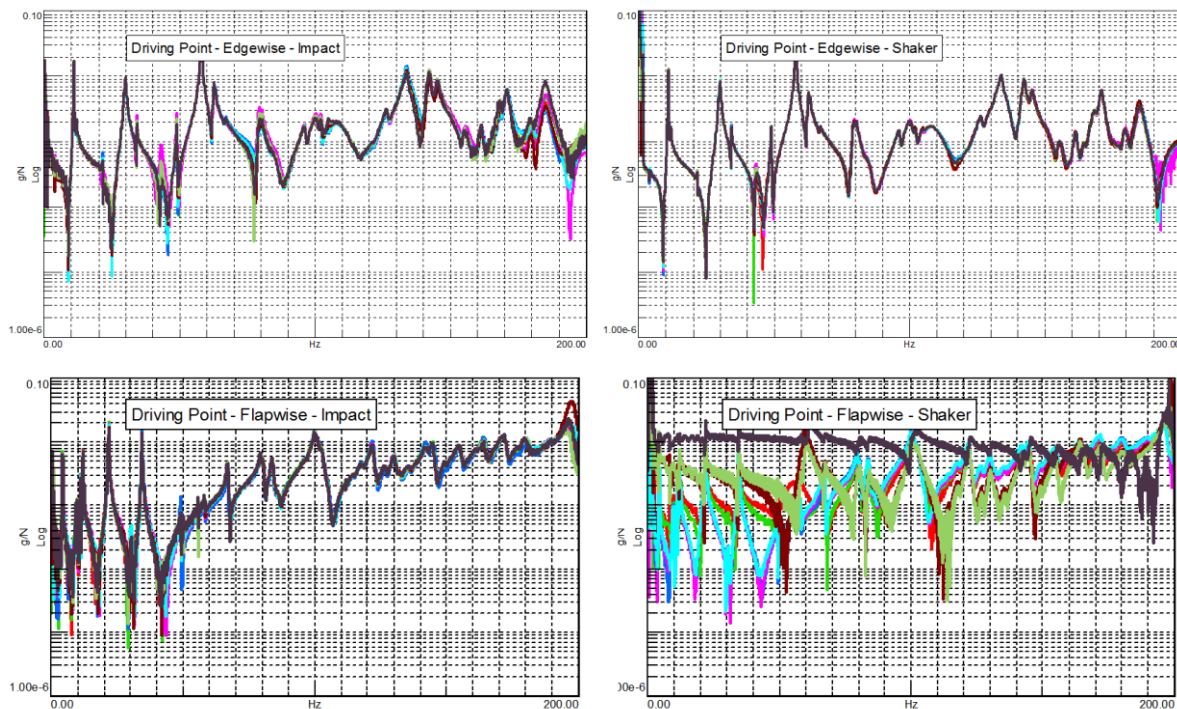


Figure 3 Repeatability analysis: Driving Point FRF over the 8 measurement runs for Hammer (left) and Shaker (right) excitation in both Edgewise (Top) and Flapwise (Bottom) direction

3.2. Modal analysis results

As explained in the previous section, both hammer and shaker testing for FRF measurements have advantages and disadvantages. As the ultimate goal of this analysis is to characterize the modal response of the turbine blade, the FRFs collected will be processed using Simcenter Testlab Modal Analysis to derive the modal parameters. Because of the repeatability achieved over the different tests, it is acceptable to merge all FRFs and process them in one go. The correlations of the natural frequencies (left) and corresponding damping ratios (right) are presented in Figure 4.

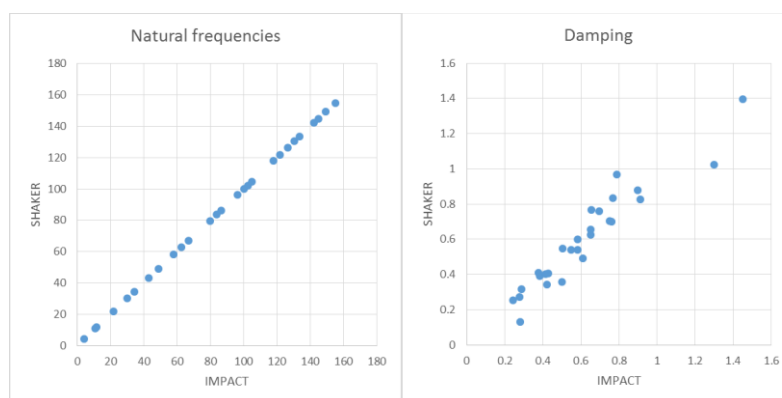


Figure 4 Correlation plot of the Natural Frequencies, Modal damping coefficients estimated from impact and shaker tests.

Natural frequencies are accurately and consistently identified in the two cases, but some differences can be observed in frequencies and damping. Damping estimates are a bit more spread, but this can be attributed to the difference in noise between shaker and impact testing: to save time, only 5 averages were collected when using the hammer, against the 50 used with shaker, thus causing noise levels to

be higher in the former. Damping is known to be affected by noise and this is what causes its higher variability between the two excitations. Finally, a generally very good correlation is observed between the mode shapes, except two cases. The first poorly correlated mode is the one at 43 Hz, corresponding to the blade 1st torsion. This is also a mode where the difference in damping is highest (1.3 vs 1 %). Overall, this mode was not optimally excited in neither of the cases, thus causing low confidence with the modes derived both from hammer and shaker testing. The other non-correlated mode is the one at 104 Hz, which shows a combined flapwise-torsion behaviour. In this case, by analysing the data and by visually animating the shape, it was clear that the impact estimate was not accurate as the modal parameter identification algorithm had trouble in identifying a stable shape due to the poor FRF quality. However, despite these small differences, the modal models from the two sets correlate very well: overall, the slightly higher uncertainty on the estimates derived from impact testing are balanced by the higher flexibility of the testing setup, which is significantly more complex when using shaker.

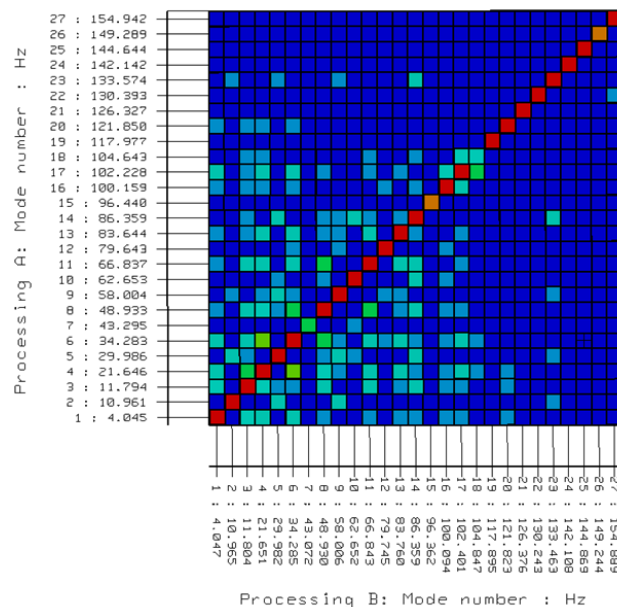


Figure 5 Modal Assurance Criterion matrix for the modal vectors estimated from impact and shaker tests.

Modal Assurance Criterion has been applied to assess the similarity of two mode shapes. For identical mode shapes from different excitations the MAC will have a value of one or 100% as shown in Figure 5. For modes which are very different, the MAC value is close to zero, as shown in Figure 5. MAC values close to 100% on the main diagonal confirm that modal vectors from impact and shaker excitation are nearly identical. Low values of the off-main diagonal terms confirm the modes are uniquely observed. Through the experimental campaign overall 120 measurement points were measured in three directions. Modal model estimation has been implemented through the multi run modal analysis approach. For each of the data set corresponding with the particular sensor station the estimation of the modal parameters has been performed. It resulted with the collection of 15 partial modal models which were merged into one global modal model of the overall structure. To compensate the variability between the recorded sets which might occur due to the mass loading and the boundary conditions change, the complete mode shapes were calculated using Driving Point scaling as presented in Figure 6. Next to the experimental activity the numerical simulations presented in Figure 7 has been performed and the results has been compared to the measurement results.

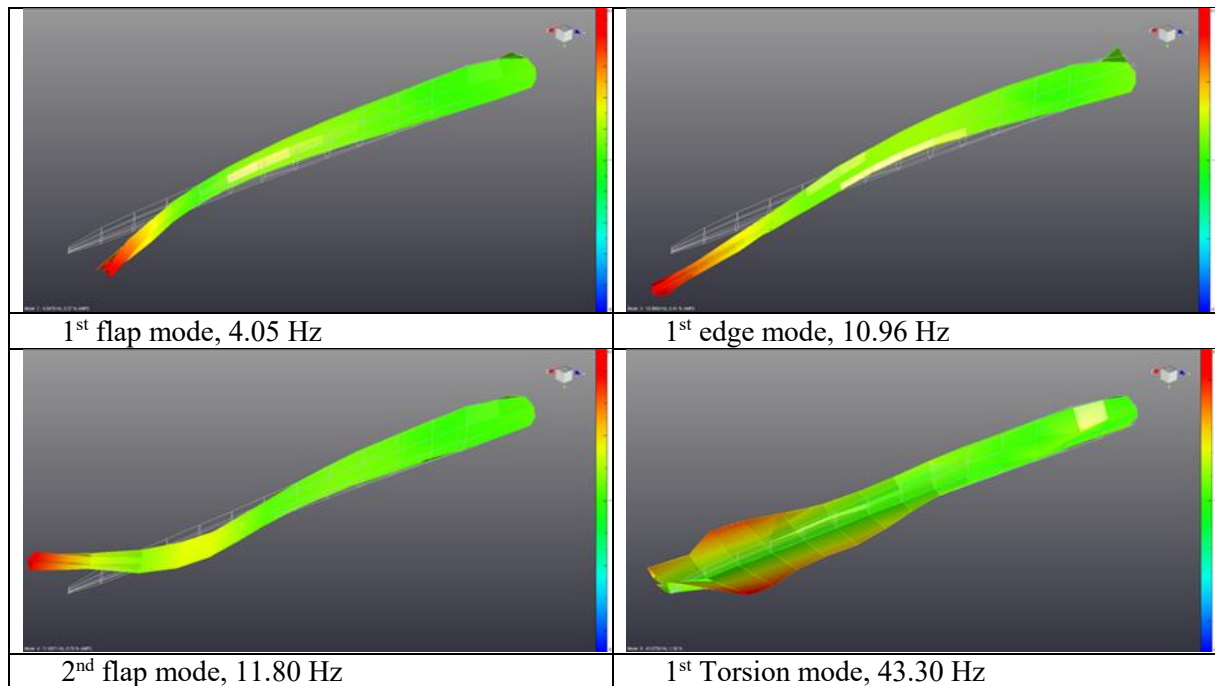


Figure 6 Experimental modal analysis results with the shaker excitation applied.

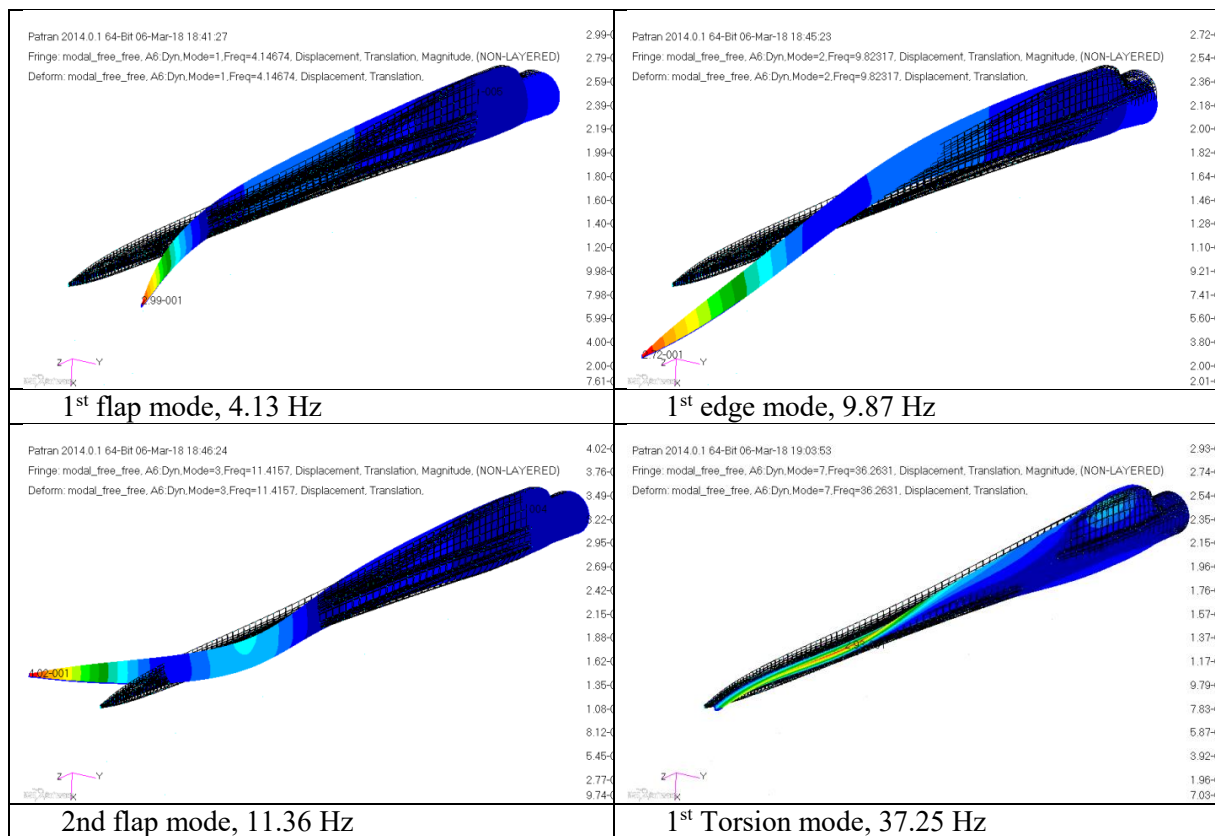


Figure 7 Theoretical modal analysis results. Calculations performed using FEA model

4. Conclusions

Presented research has been focused on assessment of the different excitation techniques applied for experimental modal testing of the same blade. Modal model parameter values estimation has been conducted based on the experimental datasets collected within both tests. In order to exclude the influence of the other test setup parameters (boundary conditions, number and location of the measurement points) these settings were kept invariant.

Impact testing in this study represents the Single Output and Multiple Input (SIMO) testing while application of two Electrodynamic shakers falls into Multiple Input Multiple Output (MIMO) method. Main difference is that in the second test configurations the shaker attachment has been set to excite both directions, flapwise and edgewise, at the same time. This is clearly the advantage of the shaker excitation. Next to it shakers are driven by a signal generator which offers different excitation signals ranging from purely harmonic through the swept and stepped sine up to random. Shaker excitation ensures the excitation force repeatability to the extent not available from the hammer testing. Impacting the structure with the modal hammer has low repeatability in terms of the force level. Important aspect of the compared tests is the duration of the tests. Impacting by modal hammer and exciting the structure with the two electrodynamic shakers took a comparable overall testing time.

Important conclusion from the comparison of the two experimental approaches is that for the investigated blade the applied excitation method has little influence on the obtained results. It proves that well established impact testing method can be successfully applied for the experimental structural dynamics identification of such large and complex structures like a wind turbine blade made of composite material.

5. Acknowledgements

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6. References

- [1] International Electrotechnical Commission. International standard IEC 61400-23 Wind turbine generator systems – part 23: full-scale structural testing of rotor blades. Wind Turbines-Part 1: Design Requirements 2014.
- [2] Avitabile P. Modal testing : a practitioner's guide. : John Wiley & Sons Ltd, 2018.
- [3] Griffith DT, Carne TG. Experimental modal analysis of 9-meter research-sized wind turbine blades. In: Anonymous Structural Dynamics and Renewable Energy, Volume 1: Springer; 2011, p. 1-14.
- [4] Griffith DT, Smith G, Casias M, Reese S, Simmermacher TW. Modal Testing of the TX-100 Wind Turbine Blade. Sandia National Laboratories Technical Report, Report# SAND2005-6454 2006.

- [5] Larsen GC, Hansen MH, Baumgart A, Carlén I. Modal analysis of wind turbine blades. 2002;Risø–R–1181(EN).
- [6] Luczak M, Manzato S, Peeters B, Branner K, Berring P, Kahsin M. Dynamic investigation of twist-bend coupling in a wind turbine blade. *Journal of Theoretical and Applied Mechanics* 2011;49:765-89.
- [7] Heylen W, Lammens S, Sas P. *Modal Analysis Theory and Testing*. 2nd ed. Leuven: Katholieke Universiteit Leuven, Departement Werktuigkunde, 1998.